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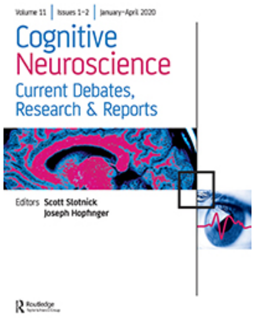

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Recording brain activity can function as an implied social presence and alter neural connectivity

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ABSTRACT
People often behave differently when they know they are being watched. Here, we report the first investigation of whether such social presence effects also include brain monitoring technology, and also their impacts on the measured neural activity. We demonstrate that merely informing participants that fMRI has the potential to observe (thought-related) brain activity is sufficient to trigger changes in functional connectivity within and between relevant brain networks that have been previously associated selectively with executive and attentional control as well as self-relevant processing, social cognition, and theory of mind. These results demonstrate that an implied social presence, mediated here by recording brain activity with fMRI, can alter brain functional connectivity. These data provide a new manipulation of social attention, as well as shining light on a methodological hazard for researchers using equipment to monitor brain activity.

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Resting state fMRI; privacy concerns; invasive technology

Introduction

It is well established that the physical presence of others can alter people's behaviour. Their social presence can affect how people talk (Walker, Risko, & Kingstone, 2014), how much they eat (Herman, Roth, & Polivy, 2003), whether they yawn or not (Gallup, Risko, & Kingstone, 2016; Gallup, Vasilyev, Anderson, & Kingstone, 2019), increase 'choking' under pressure (Belletier et al., 2015), and even influence the effect of emotional arousal (Yu, Tseng, Muggleton, & Juan, 2015). One of the central ideas driving this line of research is that the presence of others increases conformance to social norms (Guerin, 1986). Early work demonstrated, for example, that when participants were asked to sort materials with erotic visuals, they would spend less time doing so when in the presence of others versus when they were alone (Weiss, Miller, Langan, & Cecil, 1971).

Interestingly, the physical presence of another person is not necessary for such social effects. Even a simple reminder or cue that one's performance might be observed or recorded by technology (e.g. a 'live camera') can induce effects similar to when someone is actually present. Van Rompay, Vonk, and Fransen (2009) demonstrated that people were more likely to help to collect a pile of questionnaires that were dropped by a confederate in a lab when there was a security camera in the room, compared to when no security camera was present. More recently, Risko and Kingstone (2011) and Nasiopoulos, Risko, Foulsham, and Kingstone (2015) discovered that simply wearing an eye tracker can influence looking behavior. In both studies the key comparison concerned when individuals believed that an eye tracker was monitoring their looks versus when they did not. In actuality, looks were always being recorded by a camera concealed in a sexually provocative swimsuit calendar mounted on a wall in the testing room. It was participants' looking behavior toward the calendar that was of critical interest. Risko and Kingstone reasoned that if an eye tracker can operate as an implied social presence, then individuals should alter their behavior to be consistent with social norms. This is precisely what was found, with participants rarely looking at a provocative calendar when they believed that their eyes were being tracked. In contrast, participants almost always looked at the calendar when they thought their behaviour was not being monitored.

In the present study we asked if the belief that a device is recording one's performance (or not) extends beyond overt behaviour and can affect one's patterns of brain activity. In short, if people believe that a technology can 'see' their internal thoughts, will people alter what they think about? Not only do the above

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investigations support this possibility, but a recent study by Baker, Schweitzer, and Risko (2014) revealed that of all the monitoring technologies in the society today – location tracking cell phones, unmanned aerial drones, data hungry internet service providers – brain monitoring was judged to be more of a privacy violation when described as providing access to self-relevant information.

Functional magnetic resonance imaging (fMRI) represents an ideal technology to investigate this issue because it is perceived to be an especially powerful method for observing the neural correlates of thought, even by naïve participants (Racine, Bar-Ilan, & Illes, 2005). We used a 'resting state' design, where participants are alone with their thoughts, and therefore best able to ruminate on the notion that they are being observed (Damoiseaux et al., 2006; Van Den Heuvel & Pol, 2010). Specifically, by deceptively describing some functional scans as anatomical scans, we manipulated whether participants believed that their thoughts were being observed. To preview our results, we found that even this most simple of manipulations was enough to cause widespread changes in resting state activity.

Methods

Participants

Thirty healthy undergraduate students from the University of California, Santa Barbara (age range 18––22 years) who had no previous fMRI experience participated in this study, and were paid for their participation. We excluded data from one participant who reported not feeling well during scanning. Of the 29 participants whose data we included, 10 were males and 19 were females. All participants gave their informed consent; our experiment was approved by the UCSB Institutional Review Board.

Procedure

The fundamental manipulation in this experiment was to sometimes describe functional scans as structural. We used a two-part design in order to titrate the effects of interest. As participants arrived at the imaging center, they were told they would be participating in two separate studies, and were introduced to both experimenters.

Study 1 (Baseline study): After completing a safety screening and providing informed consent, an experimenter informed participants that the study sought to collect pilot data on brain activity while people are merely resting in the scanner. Participants were placed in the scanner and then informed that they would first receive a brief brain scan to ensure that they were properly positioned in the scanner; and then there would be two longer scans. One was described to the participants as a functional brain scan, and the other was falsely described as a structural brain scan (description order counterbalanced across participants). The descriptions accompanying these two longer scans were minimal: 'This scan will measure your brain activity' or 'This scan will measure your brain structure.' Besides these scan-specific instructions, participants were asked to rest with their eyes open without moving, and to simply relax. As our main research question involves how participants' brain activity changes when they believe that their thoughts are being observed, we expected that the differences between these two scans, with their brief descriptions, would be minimal.

Study 2 (Mind-reading study): Participants remained in the scanner, and the second experimenter (identity randomized across participants) informed the participants that the first study was over, and that they would be now be part of a mind-reading study that sought to examine, in real-time, the contents of their thoughts during a functional scan. Participants were also informed that, based on previous work, sexual or otherwise embarrassing thoughts were often observable.

While we let that information settle in with the participants, and to enhance the impression that they were part of a new study using a very different type of brain imaging technique while avoiding measuring responses related purely to surprise, we ran a functional scan (described as such) under the guise of ensuring that the brain monitoring equipment was working properly (we refer to this as the 'Equipment Check' Scan). We then began Study 2.

In Study 2, as in Study 1, there were two functional scans, one of which was falsely described as a structural brain scan (order counterbalanced across participants). Unlike Study 1, however, by emphasizing the mind-reading component of the functional scan, we expected that differences in brain activity between the two scans – functional and 'structural' – to be enhanced. We also directly compared the functional scans from Study 2 and Study 1 in order to further test the impact of the 'mind-reading' frame against a condition where participants knew their brain activity was being monitored, but without the explicit invasive connotation.

After Study 2 participants remained in the scanner for approximately 20 minutes, during which time they received additional scans, including an authentic anatomical scan. After exiting the scanner participants were given a questionnaire asking about their understanding of the two terms ‘functional scan’ and ‘anatomical scan’, and also exploring if their thoughts had changed during the mind-reading scan. All participants were then debriefed including a thorough explanation of the deception involved, and all of them consented to release their anonymized data for research purposes.

fMRI data acquisition

Scanning took place on a 3T Siemens Trio MRI scanner (12 channel phased-array head coil) equipped with high-performance gradients. All functional images were acquired with the following parameters using a gradient-echo echo-planar imaging sequence (TR: 2000 ms; TE: 30 ms; flip angle: 90◦; in-plane resolution: 64 × 64; 37 axial slices; slice thickness/gap: 3.0/.5 mm; voxel size: 3.0 × 3.0 × 3.0 mm; 180 volumes). Additionally, a high-resolution structural scan was collected using a T1-weighted MPRAGE sequence (TR: 1700 ms; TE: 2.97 ms, FA: 9◦; in-plane resolution; 256 × 256; slice thickness: 1.0 mm; voxel size: 1.0 × 1.0 × 1.0).

Preprocessing and data cleaning

After segmenting the structural images using FSL’s FAST, white matter (WM) and cerebrospinal fluid (CSF) masks were created for each participant by thresholding the probabilistic maps at 90%, registering (using trilinear interpolation) and downsampling to functional space, thresholding again at 0.9, and binarizing. WM and CSF nuisance timeseries were created by using FSL’s FEAT (v6.00) to carry out an initial round of preprocessing on the data that included only motion correction and brain extraction, then taking the unweighted average of all voxels within the WM and CSF masks respectively. The functional data were then entered into a nuisance regression in FEAT, which included spatial smoothing (5 mm FWHM) and registration using FEAT’s FNIRT tool (warp resolution = 10 mm). The nuisance model included the WM and CSF timeseries and the six motion parameters, plus temporal derivatives for each variable, as regressors. The residuals from this model were bandpass filtered between 0.01–0.75 Hz and transformed to 3 mm isotropic standard space using the transform generated by FNIRT, and the result was taken as our data for subsequent analyses.

Defining contrasts

Our main research question involves how social presence, vis-a-vis the belief that one’s thoughts as measured by fMRI are visible to others, affects one’s thoughts and brain activation. We operationalized this by computing contrasts between scans with different instructions that emphasized this visibility to varying degrees. Table 1 illustrates the contrasts of interest.

Each of these contrasts was designed to address the question of what happens under knowledge of observation, and they differ in terms of the theoretical magnitude of the difference between the ‘observed’ (Functional) and ‘unobserved’ (‘Structural’) scans. As noted, we expected Study 1’s Functional vs. ‘Structural’ contrast (‘Contrast 1’) to produce the fewest differences; Study 2’s Functional vs. ‘Structural’ (‘Contrast 2’) to produce the most; and Study 2 Functional vs. Study 1 Functional (‘Contrast 3’) to fall between these two extremes. We also re-ran the analyses described below controlling for the following factors: participant gender, experimenter gender, first counterbalance order, second counterbalance order, and reported understanding of the structural/functional distinction. All results were qualitatively unchanged, so we report only the uncorrected findings.

A priori *connectivity analysis*

Because we are interested in social phenomena, we used a set of *a priori* maps derived from Neurosynth (Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011) with relevant search terms to investigate changes in connectivity within and between several networks of interest. We used seven search terms, which we later combined into five broader processes. The seven terms we used were ‘attentional control’ and ‘selective attention’ (which we merged by taking the maximum at each voxel into a map we refer to henceforth as AC), ‘cognitive control’ and ‘executive control’ (which we merged similarly into map EC), ‘social cognition’ (referred to henceforth as SC), ‘self relevant’ (SR), and ‘theory of mind’ (TM). The Neurosynth search was carried out 6/25/19. To quantify intra- and inter-network connectivity, we used a multi-stage procedure to produce nodes from Neurosynth’s ‘association test’ maps. First, to make each network mutually exclusive with all others, we assigned every voxel to the map with the maximum association test value, yielding five maps with no spatial

Table 1. Schematic depiction of the three contrasts investigated in the present analysis. n/a: this scan was not included in the relevant contrast; – : this is the scan that was subtracted in the contrast; +: this is the scan from which the other scan was subtracted.

	Study 1		Equipment check	Study 2	
Contrast	‘Structural’	Functional		‘Structural’	Functional
1	–	+	n/a	n/a	n/a
2	n/a	n/a	n/a	–	+
3	n/a	–	n/a	n/a	+

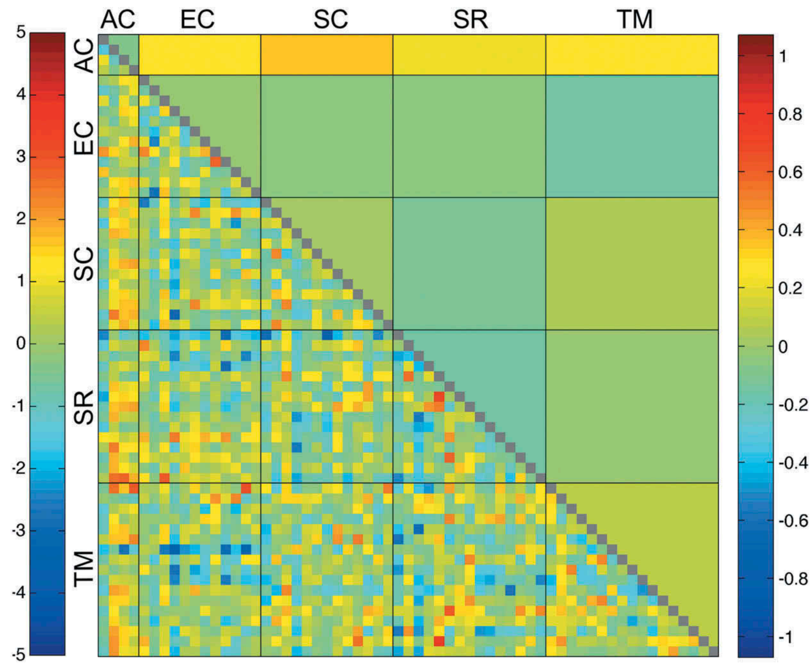

Figure 1. Connectivity results for contrast 1 between the study 1 functional and 'structural' scans. The upper triangle and right colorbar reflect effect sizes (mean/std) for each network-level region of the matrix, while the lower triangle and left colorbar show *t*-values (calculated as a one-sample *t* test within a given node-node pair across participants for contrast 1) for each individual node–node edge. Nodes within each network are ordered according to decreasing cluster size for the corresponding node.

overlap, which were then binarized. Each of these maps was then thresholded at zero, and the remaining voxels were extent-thresholded with a minimum extent of 33 voxels (66 mm^3), which was chosen heuristically based on the distributions of cluster sizes across all maps. Finally, each cluster was downsampled to match functional resolution using trilinear interpolation.

This procedure resulted in a varying number of spatially distinct nodes per network. For each node, separately for each participant and each functional run, we generated a single timecourse by taking a weighted average using that node's final downsampled map. Again separately for each participant and functional run, we computed all pairwise Pearson correlations between nodes. These correlation values were all Fisher *z*-transformed, and within-participant contrasts were computed by taking the difference between the relevant connectivity matrices for each contrast. Finally, gross network-network results were computed using a multi-level model run in R using lmer, with an intercept varying across network-interaction level as a fixed effect as well as a random intercept across participants. The resulting network-interaction intercepts and their standard errors are taken as summaries of the intra- and inter-network changes in connectivity across functional runs. Because these were planned analyses, we do not correct for multiple comparisons. We use the notation T below to refer to the ratio of a beta with its standard error, and although this is not a proper Student's *t* statistic, we conservatively compare against the critical values for a *t*-test with $df = 26$ in making determinations regarding significance.

Results

Behavioral results

A total of 22 participants reported having understood the distinction between the terms 'functional' and 'anatomical,' while seven participants did not understand the meaning of the terms. Two participants who reported having become suspicious at some point during scan were excluded from analysis. The final sample included 9 males and 18 females (age range 18–22 years).

A priori *connectivity results*

Figure 1–3 show the results of our contrasts within our set of *a priori* networks of interest. Contrast 1 was based on data collected in Study 1, and reflects the difference between the 'Structural' and Functional scans. Using the results of the multi-level model to identify significant network-level results, this contrast revealed no significant changes between scans (although the change in connectivity between the AC and SC was close, at $T = 2.01$). This finding suggests that merely

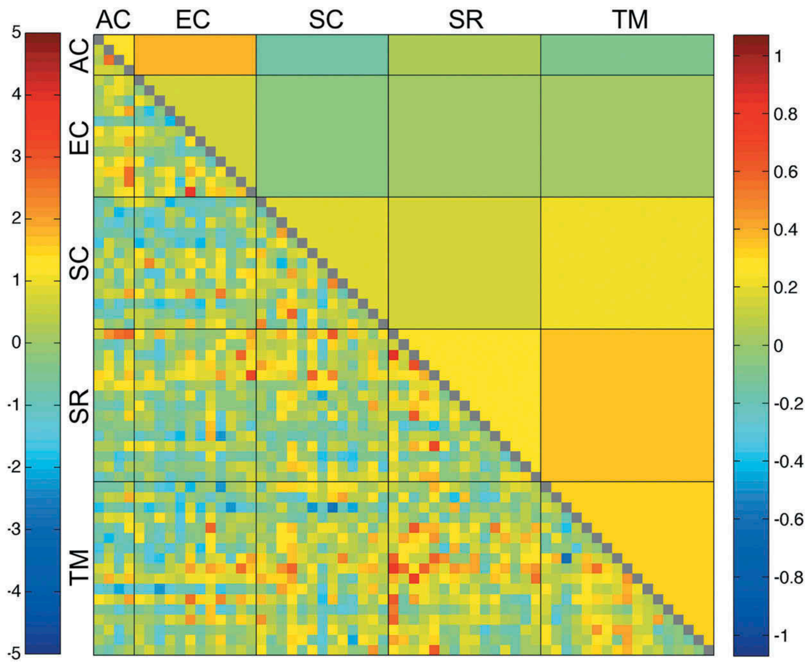

Figure 2. Connectivity results for contrast 2 between the study 2 functional and 'structural' scans. All conventions as in Figure 1.

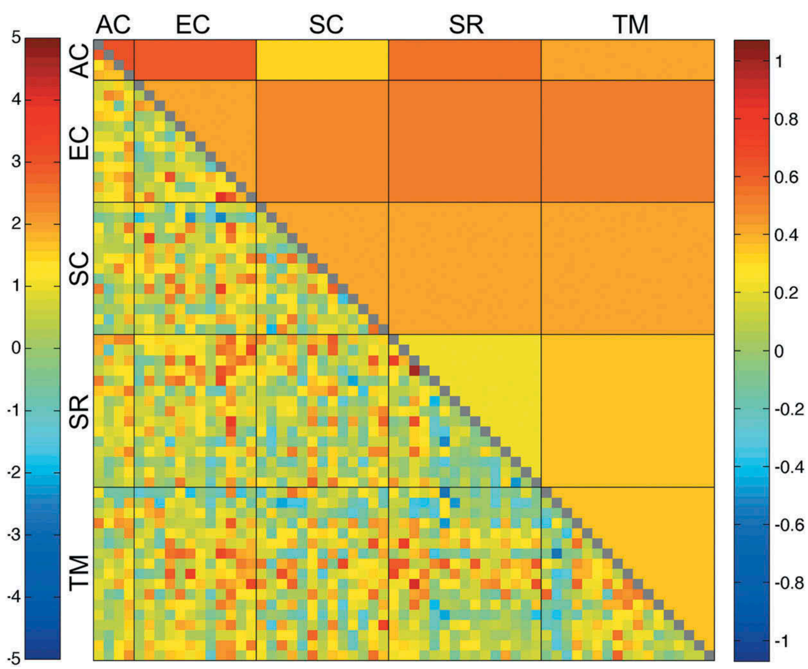

Figure 3. Connectivity results for contrast 3 between the study 1 functional scan and the study 2 functional scan. All conventions as in Figure 1.

being in an fMRI scanner and having a functional brain scan *does not* substantially modulate these brain networks differentially compared with being in a scanner and believing that your brain is being scanned anatomically.

Contrast 2 was based on data collected in Study 2, and examined changes in brain activity between its 'Structural' and Functional scans. As with Contrast 1, there were no significant changes in network-network connectivity amongst the networks we investigated here (although again, one pair, namely AC with EC, was close, with $T = 2.02$).

Contrast 3 examined changes between the Study 1 Functional scan and the Study 2 Functional scan. The results for this contrast differ starkly compared to the first two, insofar as there are only a few network pairs that fail to reach significance. For the AC network, the changes in connectivity with the EC network (T = 3.45), SR network (T = 3.11), and TM network (T = 2.22), as well as AC's change in intrinsic connectivity (T = 3.61) are all significant. Additionally, the EC network evinced significant changes with itself (T = 2.33) and every other network (SC: T = 2.58; SR: T = 2.84; TM: T = 2.77). Finally, the changes in connectivity both within the SC network (T = 2.22) as well as with the remaining networks (SR: T = 2.20; TM: T = 2.22) are significant.

Discussion

Our results contribute two novel findings. First, they demonstrate that merely providing an instructional manipulation emphasizing the degree to which a scan has the potential to observe (thought-related) brain activity is sufficient to cause changes in functional connectivity within and between relevant brain networks. This finding continues earlier work demonstrating the range of monitoring technology to which participants are sensitive, including a stationary camera (Van Rompay et al., 2009), a web-cam (Gallup et al., 2016), or eye-tracking equipment (Nasiopoulos et al., 2015; Risko & Kingstone, 2011).

It is important to consider the extent to which the present results reflect a social effect (e.g. 'these other social agents can see what I am thinking') or a recording effect (e.g. 'this machine can record what I am thinking'). While the present design does not afford a definitive test, recent research has demonstrated that implied presence manipulations, similar to those used here, do seem to depend explicitly on their social implications. For example, Gobel, Kim, and Richardson (2015) demonstrated that implied presence effects are abolished when people believe that camera recordings will not be viewed by another person. And more recently, Gallup et al. (2019) have shown that presence effects are eliminated when an avatar in an immersive virtual reality (VR) environment is *not* a stand-in for a real person, or similarly, a webcam situated within VR environment is not transmitting a recording that can be viewed by an actual person. Thus, it seems reasonable to suggest that the present findings are social in nature (i.e. people believed that their brain activity would be observed by another person). We hasten to add, however, that one outstanding question for future investigation is whether an implied social presence effect on overt and covert behaviours are mediated by the same or different mechanisms. For instance, it is possible that unlike the implied social presence effect of a camera on overt behaviour, which may be mediated by a 'spotlight effect' – that is, the tendency for people to overestimate the extent to which their behavior is evaluated by others – the presence effect of fMRI technology on covert brain activity may be mediated by a different cognitive bias known as an 'illusion of transparency', which results in people overestimating the extent to which their internal thoughts are apparent to other people. Note that in both cases, a common link is the importance of the 'social other' (Gilovich & Savitsky, 1999).

Second, our results elucidate the neural correlates of implied social presence in five relevant brain networks, namely, networks that have been previously associated selectively with attentional and executive control, as well as self-relevant processing, social cognition, and theory of mind. Our results suggest that instructional manipulations are not guaranteed to cause changes in the patterns of connectivity within and between these networks, as demonstrated by the lack of significant network-level connectivity changes in Contrasts 1 and 2 (although the lack of significance in these contrasts could reflect smaller effects that fail to achieve significance given our sample size). However, given instructions that more explicitly refer to the invasive nature of the technology, there were widespread significant changes in network-level connectivity patterns, involving all five examined networks. From this perspective it will be important to consider the nature of the neural mechanisms activated by the idea that one's thoughts are being monitored by another social agent.

One interesting possibility is that individuals actively monitor their thoughts and attempt to suppress certain classes of thoughts, for example, thoughts the individual might deem 'embarrassing' or in some manner socially unacceptable. There is an extensive literature in psychology on thought suppression which has typically demonstrated a paradoxical increase in the to-be-suppressed thought (Wegner, Schneider, Carter, & White, 1987). Previous fMRI studies of this phenomenon have identified activity in regions that the authors claimed reflected cognitive control, such as the anterior cingulate and dorsolateral PFC (Mitchell et al., 2007; Wyland, Kelley, Macrae, Gordon, & Heatherton, 2003). Unfortunately, from these studies (which focused on activation), it is difficult to predict how functional connectivity might be modified due to thought suppression. Our design also does not allow us to distinguish between changes that are due to alterations in the underlying thoughts *per se* (either paradoxical increases due to attempted suppression or attempts to focus one's thoughts on an unembarrasing topic), versus changes in regions involved in monitoring/control.

Note, however, that our goal was not to resolve these possibilities, and indeed, we do not regard the possibility that our results reflect (at least in part) thought suppression as a limitation. We are interested in the neural analog of the behavioral changes participants exhibit when they are being outwardly observed. However they manage that – for instance, whether they engage in a strategy of attempting to suppress certain types of thoughts in response to our instructions, or focus their thoughts elsewhere – they are nonetheless doing so because they believe their thoughts are being monitored. We look forward to future research that seeks explicitly to identify the effects of brain/thought monitoring to disentangle these (and likely other) potential mechanisms.

One other observation emerges from our work, with potentially far-reaching consequences, with the caveat that this issue was not something our study was explicitly designed to address – and that is, all fMRI studies are subject to the sort of effect we describe here (again, whether it is due to implied social presence or some other mechanism). Although the effects were nonsignificant for the mildest instructional conditions (which likely replicates the norm for most studies), our results may nonetheless be a cause for concern in three specific situations. First, all studies of resting-state fMRI may carry a weak trace of this observation effect signal (which may emerge when aggregating across the many studies that have examined the resting state in recent years). This is not necessarily a confound, but it is at the very least something researchers should be aware of, and perhaps would prefer to minimize by using instructions that do not accentuate the observational or social nature of fMRI. Second, all studies that are interested in social processes and therefore (intentionally and by necessity) activate social concepts in their participants are likely to also be activating the sorts of processes we describe here, whether intentionally or not. And third, any study that draws from a population that might be especially susceptible to the phenomenon described here – for instance, individuals with delusions of observation or those with social anxiety – might be particularly influenced by changes related to this observation effect, rather than whatever process the experimenters intended to study. However, as our study was designed to discover *if* fMRI triggered a presence effect rather than to elucidate such an effect's neural underpinnings, we describe these possibilities only as reasonable inferences based on our results, and propose that they warrant further investigation.

These results lay the groundwork for future researchers interested in understanding the neural and cognitive effects of implied social presence and invasive monitoring technologies. They also serve as a caution for researchers interested in studying other processes without contamination from processes related to implied social presence, and suggest that these researchers should ensure that their instructions to participants are relatively minimal, so as to avoid invoking processes and concerns of mind-reading in their participants. Especially as the technology continues to improve and claims of fMRI's mind-reading potential become more widely (mis)reported in the popular press, it will become increasingly important for researchers to be aware of the effects that their measurement tool have on the object of their measurement itself.

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Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability

Unthresholded statistical parametric maps will be uploaded to a public repository (neurovault.org). Code and scripts used in analysis will be made available upon request.

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